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Study of Cooling Mode of Heat Mine Based on the principle of CCHP

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Abstract

This paper analyzed thoroughly each kind of reason which has created the coal mine shaft hot evil, in the reasonable computation mine shaft cold load's foundation, taking the hot evil well by the gas power set's exhaust afterheat and cylinder jacket -odd hot water to fall the tepid power to originate, has designed one kind of mine shaft temperature decrease patterns which based on the thermoelectricity cold payment proportional to production principle, and carried on the technical economy and the hot economic analysis contrast between lithium bromide refrigeration and electricity refrigeration。 It conducted the related research for the later period to propose one kind of new mentality.

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Keywords: CCHP; high evil mine pit; lithium bromide refrigeration unit; temperature decrease pattern discussion

1. Introduction

Mine thermal environment which used to call it mine heat-harm refers to the combined effect and function by micro-climate such as temperature, humidity, wind speed and thermal radiation to body heat. With further increase of mining depth, the problem of mine heat-harm will be more serious. So the heat injury is bound to the major technical issue should be faced to.

Most of the existing air conditioning systems of mine use large grid electricity that is purchased electric refrigeration, which is not only large power consumption itself and high cost, and also increasing

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power shortage and electricity expensive situation, thus the resulting high costs will lead to the coal mining economic decline. So it is our high coal mines are used to the art of a prominent problems.

At the same time, most of high evil mine pit will be associated with coal mine gas. If we can full use of the gas of very good heating value to build pit thermal power stations, which collocate he absorption chiller that is studied by pit thermal power stations, producing mines of the high temperature and the cold surface needed for the construction, will greatly improve mine's economic benefits, reduce greenhouse gas emissions, and greatly improve mining environment. It is a very economical and environmentally coal thermal damage model.

2. Analysis of high evil mine pit

There are many reasons which causes mine thermal damage, generally we could analyze them under the following aspects:

2.1 The influence of surface air temperature.

As the statistical data shows, there was a certain periodical change about the surface air temperature, so that air temperature of the inlet-air routes of mine cyclical changes accordingly. This change will reduce with the distance from the wellhead into the wind increased, and for the time, the change of temperature in the pit lags that of surface a bit.

The statistical estimation formula:

$$t = t_0 + A_0 \sin\left(\frac{2\pi\tau}{365} + \varphi_0\right) \ ,℃ \tag{1}$$

Including: t_0 —The average temperature of surface, ℃;
τ —Time,d;
φ_0 —Initial phases of function, rad;
A_0 —fluctuation amplitude of surface air temperature;

The calculation formula: $A_0 = \frac{t_{\max} - t_{\min}}{2}$, $t_{\max}$, $t_{\min}$ are the annual highest monthly temperature and lowest monthly temperature.

2.2 The influence of coal and rock temperature.

Geothermal heat in coal mines is always the most important reason for damage. The temperature of coal and rock roadway is undoubtedly the most important source of geothermal. As related data shows, when entered into the temperature-constant area underground, the temperature gradient of surface will gradually increase, with temperature increasing, the impact on the operations side will be more and more obvious.

Because of the special structure of coal seam and its impact on the tunnel air, it is unrealistic to accurately calculate the temperature of the roadway surrounding rock and coal seam. If we simplify assumptions and the fluid in the roadway to turbulent fluid, then its estimation formula of temperature can be calculated according to Newton's law of cooling:

$$Q_r = K_\tau UL(t_r - t\ ); \quad \text{KW} \tag{2}$$

Including: Q_r —heat transfer from roadway surrounding rock;

K_τ —Unstable heat-transfer coefficient between the airflow and rock, $\text{KW/m}^2.℃$, according to experience it could be worth as 2;

U —Tunnel circumference， m;

L —Tunnel length， m;

t_r —The average original temperature between both ends of the roadway;

t —The average air temperature flowing through both ends of the roadway, ℃.

2.3 The influence of cooling of large electrical and mechanical equipment.

Electrical and mechanical equipment underground includes tunnelling equipment and electrical transportation equipment. It is one of the reasons which cause increasing of air temperature in the tunnel to release heat in the work.

Calculate the cooling of tunnelling equipment:

$$Q_c = \varphi N, \quad \text{KW} \tag{3}$$

Including: Q_c —The heat absorbed by air flow， KW;

φ —Heat-absorb scale factor of exothermic of tunnelling equipment operating in the endothermic heat ratio factor; value of ψ can be determined by statistics.

N —Actual power of tunnelling equipment, KW;

Electrical equipment exothermic calculation can be carried out in accordance with the following formula:

$$Q_e = (1 - \eta_t)\eta_m N, \quad \text{KW} \tag{4}$$

Including: Q_e —Exothermic of electrical equipment， KW;

N —Power rating of electrical equipment, KW;

η_t —Mechanical efficiency of elevate equipments, other equipments or puts matter η_t = 0;

η_m —Combined efficiency of electrical equipment, including the load factor, daily operating time and the motor efficiency and other factors. For some mines, the following formula can also be used to estimate the cooling of the electrical equipment as a whole:

$$Q_s = \sum_{i=1}^{n} 0.1 N_i \tag{5}$$

Including:

Q_s —Total heat of electrical equipment and preventer, KW;

N_i —efficiency of equipment I, KW;

n—The number of mechanical and electrical equipment in tunnel;

2.4 The influence of various oxidation heat and cooling of protective equipment.

Exothermic from oxidation, blasting heat, the body cooling, protective equipment cooling and other gangue transportation may occur in the process of coal Sinotrans. At the same time the local air temperature will increase. As the test data show, air flow through the coal seam before and after moving, air temperature increased by about 1℃.

Within a variety of oxidation, the oxidation of coal and gangue is one of the main reasons. The oxidation process is relatively complex. We generally use the following formula to estimate:

$$Q_0 = q_0 V^{0.8} UL\text{, KW} \tag{6}$$

Including: Q_0 —Heat release of oxidation, KW;

$V^{0.8}$ —The average wind velocity in tunnel, m/s;

q_0 —When V＝1m/s，h eat release of oxidation per area, KW/m2; in the absence of measured data we worth it 3～4.6×10-3 KW/m2.

2.5 The influence of temperature of groundwater evaporation.

When the water temperature is lower, the evaporation would significantly reduce the downhole temperature; On the contrary, if the groundwater and high temperature hot springs are connected, it will increase the temperature in the pit.

3. Cooling Projects

3.1 Description of the Project

WangYing mine mouth power plant which belongs to Fuxin Mining Group Co., Ltd. is located in WangYing mine, modest distance from extracting/discharging station as South of Wang Ying Coal, the north wind well and the south wind well of Wu Long mine, so it can reduce the distance of gas pipeline transmission. And it is easy to external input because of nearing converting station and heat load.

CBM for power generation is the mixed underground extracting/discharging after quenching gas which separately from extracting/discharging stations as Liujianan wind well of Wu Long mine, Wangyingbei wind well and Wangyingnan wind well. Calculated by the greatest number of mine drainage volume, Total volume is 204,000 m3/d, CH4 concentration of 34%, equivalent to pure CH4 to 68,300 m3/d.

Technical parameters of gas:

According to the analysis data on mine drainage of CBM and the theoretical data after mixing the ground drilling air provided by the CBM, technological parameters of the coal bed gas which entered into the power plant are as follows:

chart 3.1 Typical ingredients of underground coal bed gas

ingredients	CH_4	N_2	O_2	CO_2	C_2H_6	C_2H_6	H_2S
content (%)	33.96	59.31	4.9	0.53	0.14ppm	0.92ppm	microscale

Lower calorific value: 12.5MJ/m3
Calculation flow: Wind well of Wangyingbei 5375 Nm3/h（$CH_4$34%），
Wind well of Wangyingnan: 3125 Nm3/h（$CH_4$34%），
Technical indicators of the power plant:
Installed capacity: 500KW×20 sets＝10000KW;
Electric energy production: 204900 kwh/d（ 1Nm3 pure CH4 can produce electricity 3kwh）;
Power voltage: Unit 400V, output outside the station 6KV;

3.2 The main process of underground cooling

The power station is designed to be CCHP mode gas-based thermal power stations. Its features is that gas source is the drainaged gas from the mine, waste heat can be fully utilized: When temperatures is higher in summer and we need not provide heat for users, it take cold through the lithium bromide absorption chiller system and through the pump station that transported cooling capacity to the underground; When winter arrives, underground temperature is not high enough to be a heat injury, refrigeration units can be partially closed, a lot of waste heat can be piped to the office or residential customers for heating. The technology improves the thermal efficiency and also achieves the purpose of environmental protection. It is one of the most economical and environmental ways of using gas in the thermal damage and high gas mining. The basic process is as follows:

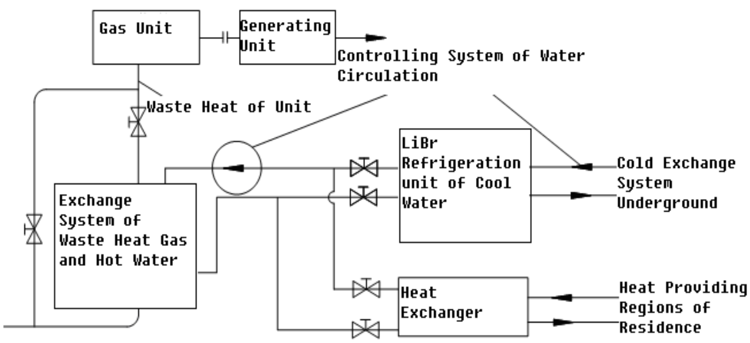

Figure3.1 Basic Process Chart

3.3 Optimization of designing load calculation and cooling system

3.3.1 Load calculation of refrigeration

As noted above, the total cooling load of the whole system should be:

$$Q = k(Q_r + Q_c + Q_e + Q_0 + Q_q) \tag{7}$$

Including: Q—total load of refrigeration, KW;
k—extra-coefficient, to consider the loss of refrigerant and ventilation systems, cooling system layout and other factors, some of the excess refrigeration capacity due amount, so the surplus coefficient is generally taken to be 1.05~1.1;
Q_q—Other cooling load, KW;

Other indicators as above.

Known through the field measurement, the temperature of mine fully mechanized face is 33°C, temperature of extraction chamber is 34.5°C, in combination with other thermal parameters of the underground calculations indicate that the total cooling load of mine is Q = 4200 KW.

Based on 2007 version of the national mine safety regulations, temperature of mine surface fully mechanized should be lowered below 26 °C.

3.3.2 Setting and selection of cooling station in the ground

Ground cooling station generally is sited in the best balance between power stations and pit location according to the actual situation, in order to reduce heat loss and improve overall thermal efficiency.

Absorption chillers consist of lithium bromide and ammonia refrigeration unit. Lithium bromide absorption refrigeration cycle unit is especially suit for air-conditioning works because of its smooth running, low noise, energy adjustment range, easy to maintain, the low-grade heat and a series of advantages. It is undoubtedly one of the best choices for mine cooling.

According to the field measurement data, the heat parameters of ore used by the exhaust gas recovery unit are as follows:

Temperature of flue outlet: between 500°C and 550°C;Gas flow: qυ=2130Nm^3/h;Gas density: ρ=1.293kg/ Nm^3;Flue gas heat: C=0.257kcal/kg. °C； Temperature of unit circle circled: around 140°C.

Known from analysis and reference of the design parameters, on the whole it is suitable to use the gas / hot water double effect lithium bromide absorption chiller. As the outlet temperature of lithium bromide chiller cold water are only three parameters as 7°C、10°C、13°C in the current industry standard in China, route of pipeline underground is long, it may not meet the cooling needs of underground, therefore, we need to auxiliary set of electric refrigeration equipment in order to make the temperature of the cooling system water reach -2~0°C and the temperature of return water at 16~18°C.

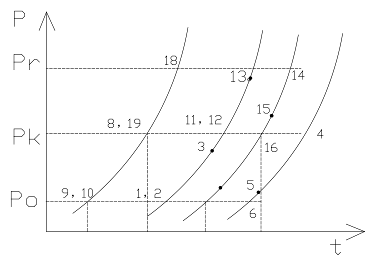

Figure 3.2 p-t diagram of double-effect lithium bromide absorption refrigeration

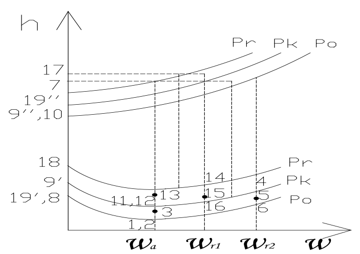

Figure 3.3 h-w diagram of double-effect lithium bromide absorption refrigeration

3.3.3 Design and layout of underground refrigerate system

Entire refrigeration system is designed as closed-loop water cooling system, in which the temperature of the output water of lithium bromide refrigeration system which forms cooling high-pressure side water of -2~0℃ through further cooling by the screw-type electric refrigeration unit is 7℃. It is transported after pressurized by freezing pipes to heat exchange station underground through the wind well by insulation pumps (usually laid in a special cave), in order to complete the closed cycle of high-pressure side during the process that it return to the ground lithium bromide chiller evaporator after exchanging heat with low pressure-side cold water; in the refrigerant distributor underground (high and low pressure heat exchange station), the low-pressure chilled water after the exchange of working medium is pumped through the heat transmission pipes to Air Coolers of excavation. It formed low-pressure closed circuit after indirect exchanging between cold water and airflow and returning to the heat exchange station underground.

Taking into account the problems of temperature rising caused by loss of cold in transmission and the factors of pressure dropping, cold water heat exchanger pipe which is delivered to the mine face underground is needed to be insulated, and to take necessary calculations, so we can get more suitable diameter to reduce the loss of cooling. Pipelines could be parallel lay along the tunnel underground and vent line.

Merit of this design is that we can choose the rational combination of chiller flexibly. We can turn off the refrigeration unit when the underground temperature quickly dropped to a certain extent (such as cooling to 25 ℃ below), and only operate lithium bromide refrigeration unit to maintain the underground temperature in order to save power. When the underground temperature is above 26 ℃, electric refrigeration unit is re-opened for the auxiliary cooling. Power generated by gas generator can completely supply power for the whole chiller system. This also saved large cost of cooling for the mining from the economic level.

For some mine that heat damage which is not serious and short pipelines can cool by using lithium bromide refrigeration unit to achieve the purpose of reducing heat injury.

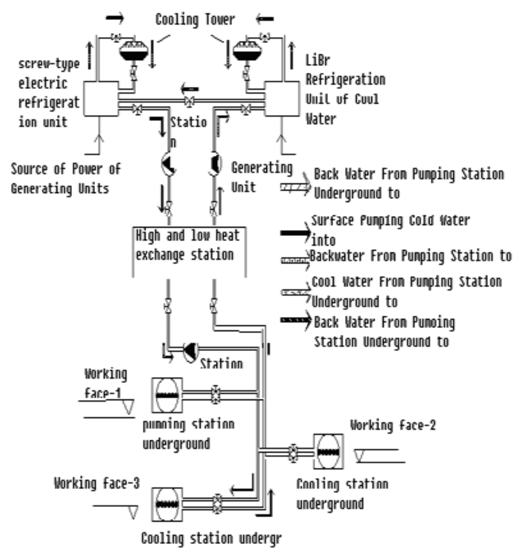

Figure 3.4 Schematic diagram of underground cool-exchanging system

4. Analysis of technological economy and thermal economy

4.1 analysis of technological economy

From all aspects of computing, refrigeration system of joint production has a unique advantage. We select lithium bromide refrigeration unit + electric cooling system and centralized electric cooling system to be compared on initial investment and operating costs of equipments.

4.1.1 Comparison of investment of basic equipment

In this scenario, we need to import a lithium bromide refrigeration unit with cooling power of 3000kw and a screw-type electric refrigeration unit with cooling power of 1200kw. The initial investment is about 5 million, of which, the lithium bromide refrigeration unit about investing 3 million, screw-type electric refrigeration unit about investing 1.5 million and other costs about 50 thousand.

The pre-equipment investment is about 250 thousand if all use of electric refrigeration unit. Difference between the two initial investments in equipments nearly doubled. In the short term, it seems that electric refrigeration unit only is more cost-effective for enterprises.

However, in the long run, mixed units or lithium bromide refrigeration unit has a greater advantage. We use the average price in 2008 as the benchmark price of an economic evaluation of the raw data, you can see:

In Fuxin, the average industrial electricity price is 0.82 ￥ / kwh. To work 12 hours a day by hybrid electric refrigeration unit (the remaining time to operate lithium bromide refrigeration unit only), it needs to consume about 14400kwh, the electric charge is about 11,800 ￥ per day. If we use electric refrigeration unit, it needs to consume 84000kwh per day, the electric charge is about 68,880 ￥ per day.

According to that a refrigeration cycle is 3 months, CCHP system with electric cooling electricity can save about 5.14 million every a refrigeration cycle.

It should be emphasized that the application of this program is the CCHP system (gas power generation and heating system design in a separate article), therefore, units can self-generate the electricity supply required for cooling, which can save a lot of extra electricity cost in another side.

The savings of refrigeration in some mines where heat damage is not a particularly serious that use lithium bromide refrigeration unit for cooling will be even more impressive.

4.1.2 Comparison of operating costs

In general, the unit's operating costs concentrated in labor costs, electricity costs and fee of equipment depreciation. For lithium bromide refrigeration unit and screw-type electric refrigeration unit, maintenance requirements and maintenance costs on lithium bromide refrigeration unit should be significantly higher than screw-type electric refrigeration unit because of the unit's precision and security factors of strict requirements.

However, heat-type or smoke / heat lithium bromide refrigeration units are more economy than the screw chillers unit only(or compression refrigeration units) from the comparison of energy consumption of cooling capacity as noted above because heat-type or smoke / heat lithium bromide refrigeration units use the heat of power station and no longer need to re-enter a lot of power. This is also offset the costs of the initial investment of equipment and unit maintenance costs.

4.1.3 Analysis of increasing efficiency of production under cooling conditions

Some studies showed that when underground temperature decreases by 1 ℃, the efficiency of workers will increase 6% to 8%; On the contrary, when underground temperature increases by 1 ℃, the efficiency ratio will drop accordingly. We have known from the calculation that the underground temperature can reduce 6 ~ 8 ℃ by refrigeration units, and can improve the efficiency of the workers by 40%.

Take a cooling period of three months for example, a working face after cooling can produce coal by 90000t monthly, then we can know:

$$\Delta Q = Q \times \eta\% = 90000\text{t} \times 40\% \times 3 = 108000\text{t} \tag{8}$$

$$\Delta P = \Delta Q \times P = 108000\text{t} \times 650 = 70.2 \text{ million} \tag{9}$$

Including: ΔQ —Growth of production after cooling, t;

Q —Total production after cooling, t;

$\eta\%$ —Efficiency index;

ΔP —Income of coal increased coal per ton, ten thousand;

P —price of coal per ton.

Known from the analysis above, when we low the underground temperature, the work efficiency and economic efficiency can significantly enhance. Compared to investment in and maintenance costs of equipment, the cooling method can obviously make more benefit, and can get the repayment of investment quickly within a very short period.

4.2 Analysis of thermal economy

We generally research thermal economic of the refrigeration units by the laws of thermodynamics. Either the first law of thermodynamics or the second law of thermodynamics, the studies are only different in angles, but the objects of study are the same.

According to the first law of thermodynamics:

$$\eta = \frac{Q_1}{Q_2}\% \tag{10}$$

Including: η—Thermal efficiency of units, which is also cooling coefficient;

Q_1 —Effective thermal power, kw;

Q_2 —Total thermal power input, kw.

From the above, we know the overall energy utilization of refrigeration system. Known from calculating, the thermal efficiency of refrigeration units is 85%, the overall use of energy is good.

According to the second law of thermodynamics:

$$\eta_e = \frac{E_e}{E_{in}}\% \tag{11}$$

Including: η_e—Energy efficiency of unit;

E_e —Effective energy, Kcal/kg;

E_{in} —Total energy input, Kcal/kg.

By contrast calculation, we know that the fire efficiency of units is 33%. This is not to say that there are contradictions between the first law of thermodynamics and the second law of thermodynamics, instead, they both remains the same in essence. The main reasons for this conclusion are the changing of tastes of energy the whole unit applied, heat loss during transfer process, cooling loss during transmission, cold flow, diameter and other factors in together. Therefore, its conclusions that simply analysis of the efficiency of energy under the second law of thermodynamics may be not match with the actual utilization of energy. Taking into account the application of lithium bromide refrigeration units are the smoke and over water with waste heat, in aspects of the recycling efficiency of energy, this design is desirable.

5. Conclusion and Outlook

The cooling of thermal damage mine is a very economical model to use energy in CCHP mode sourcing from coal gas. It not only reduced pollution of gas emitted directly, but also achieved step-use of energy, thus, its basic characteristics are economic, environmental and high performance; In the conditional mine, we can play the whole system better energy efficiency by using lithium bromide absorption refrigeration units to cool and heat cycles; The key is optimization of piping and diameter structure to make full use of waste heat which is from electricity generating by gas to cool underground according to the analysis of thermodynamic calculation, so that it is only reasonable path and diameter that can effectively reduce the loss of heating and cooling; With the improving of CCHP technology and the continuous improvement of gas utilization technologies, such an economic and environmental model will be widely applied. To spreads the use of CCHP technology in the vast mine, it is signific for the increasing of economic efficiency, strengthening the labor protection underground and reducing pollution.

References

[1] GAO Hong, Aili Zhang. Technologies And Applications o f New energy. Beijing: National Defence Industry Press, 2007. (in Chinese)

[2] Wenge Liu, Xiaosu Yu. Analysis of Chinese Mine Gas Power Generation and Its Potential. China Power, 2004,37 (4). (in Chinese)

[3] Juanyan Guo, Dongxiang Jiang, Zhao Gang. Current Situation and Problems in Technology of Generating Power by Coalbed Methane. Chinese Coalbed Methane, 2004,1 (2) (in Chinese)

[4] Piliang Ma, Chenggong Cai. Situation and Developping Strategy of Chinese Coal Mine Gas Comprehensive. Science and Technology of Coal, 2007,35 (12) :7-12. (in Chinese)

[5] Wang Yong. Study of Mine Gas Power Generation CCHP Technology. Mine Automation ,2006,5:1-9-11. in Chinese.

[6] Li Hong. Exploration and Practice of Utilization of Coal Mine Gas. Chinese Coalbed Methane, 2006,3 (4) :21-23. (in Chinese)

[7] Yuanbo Hong. Choice of CCHP Modes and Chillers. Civil Engineering and Architecture in Guangdong ,2005,8:18-19. (in Chinese)

[8] Wang Wei. Study and Design of Mine CCHP with Cooling System. Hefei Industrial University, A Master's Degree Thesis, 2006. (in Chinese)

[9] Xiu jun Wei, Chunsheng Hu. Study Heat - Electric - mine glycol cryogenic cooling technology and Its Applications. Safety and Environmental Protection Of Mine, 2009,36 (3) :20-22-25.(in Chinese)